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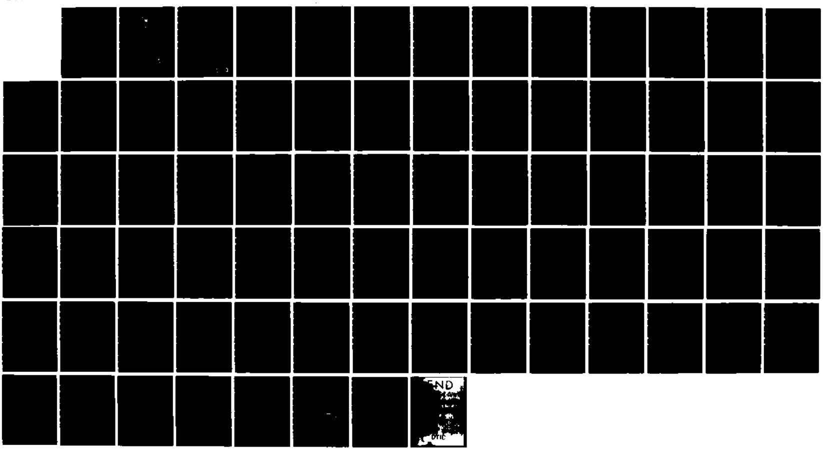

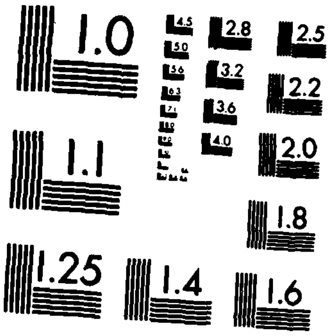
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PERFORMANCE EVALUATION OF A-10 AIRCRAFT MAINTENANCE UNITS AND AIRCRAFT USING CONSTRAINED FACET ANALYSIS

THESIS

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AFIT/GLM/LSM/84S-26

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THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

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Captain, USAF

September 1984

Preface

The purpose of this study was to evaluate the performance of A-10 aircraft maintenance units and aircraft. The study was also a vehicle to demonstrate the applicability of Constrained Facet Analysis to performance evaluations of aircraft maintenance in the Air Force.

Results showed that Constrained Facet Analysis is a promising model for Air Force performance evaluations. Work should be continued in this area to refine the use of Constrained Facet Analysis for Air Force maintenance management.

Throughout the preparation of this report I have received help from a number of people. I want to express my gratitude to Lt Col Charles T. Clark, my advisor, for his infinite patience and wisdom. Thanks also to Lt Col Richard L. Clarke for help in the correlations, and to Capt Clinton F. Gatewood for his help and advice as a reader. Finally, a special heartfelt thanks to Larry Stone for his encouragement and support throughout this endeavor.

Valerie J. Gonnerman

Table of Contents

Page

List of Figures

List of Tables

Abstract

Performance evaluation is required to obtain important feedback on system efficiency for management decision making. For Air Force aircraft maintenance managers, performance evaluation is crucial for determining capability and evaluating unit efficiency and effectiveness. This thesis effort applied Constrained Facet Analysis (CFA), a linear fractional programming technique, to the performance evaluation of aircraft maintenance units (AMUs) and aircraft. Empirical data for three AMUs covering a five month period of time and simulated data for 28 aircraft was evaluated using the CFA and Data Envelopment Analysis (DEA) computer programs at the University of Texas. Results show that CFA and DEA can be used to evaluate relative efficiency of Air Force units.

PERFORMANCE EVALUATION OF A-10 AIRCRAFT MAINTENANCE UNITS AND AIRCRAFT USING CONSTRAINED FACET ANALYSIS

I. Introduction

General Issue

Decision making is a key activity and often difficult problem for managers. Good decision making hinges on the quality and appropriateness of the information available to managers. Performance evaluations provide information inputs into the decision making process. For Air Force maintenance managers, performance evaluation is crucial for determining capability and evaluating unit efficiency and effectiveness. This research considered the evaluation of Air Force aircraft maintenance units and aircraft using the Constrained Facet Analysis (CFA) technique developed by Lt Col Charles T. Clark (11).

CFA was used to determine relative performance, or efficiency, of A-10 maintenance units and aircraft. The A-10 evaluation was based on actual data for aircraft maintenance unit (AMU) performance and simulated data for individual A-10 aircraft. The relative performance of the A-10 units and aircraft studied was measured in terms of mission capable time, sorties flown, and other measures related to availability, and did not refer to inflight performance characteristics such as handling and maneuverability.

This research was useful for two reasons: it provided a performance evaluation of A-10 aircraft and maintenance units for use by Air Force maintenance managers, and it contributed to the body of knowledge concerning CFA and its applicability to management decision making.

Specific Problem

This research addressed the applicability of CFA as a performance evaluation technique for aircraft maintenance management. Specifically, the 354 Tactical Fighter Wing at Myrtle Beach AFB was evaluated based on a five month period of maintenance data. The data on A-10 aircraft and their supporting AMUs were used to identify inefficiencies and evaluate possible causes. This research did not intend to correct deficiencies but to direct management attention to areas that require further study.

Definition of Terms

To aid the reader's understanding, the following terms are defined as they were used in this thesis.

1. Aircraft Maintenance Unit (AMU) refers to the maintenance organization that performs direct on-equipment labor on assigned aircraft and that is responsible for the management of all maintenance actions performed on the designated aircraft. AMUs are found in the Tactical Air Forces operating in accordance with MCR 66-5. An AMU is

paired with, and supports, a specified flying squadron. Generally, an AMU is responsible for approximately 20 aircraft.

2. Decision Making Unit (DMU) is the organizational entity being evaluated by Constrained Facet Analysis.

3. Effectiveness is a measure of how well the objectives of a system are met. It does not necessarily refer to how efficiently inputs were used to achieve those results (7; 12).

4. Efficiency is similar to performance for purposes of this thesis. Efficiency refers to how well inputs were used to obtain outputs (12).

5. Frontier in this thesis means the efficient aircraft or efficient AMUs. Inefficient aircraft or AMUs are compared to a subset of efficient aircraft or AMUs on the efficiency frontier. The frontier concept is similar to the isoquant concept of economics. A pictorial representation of a frontier is given in Figure 1. Note that a frontier can be shown graphically in two dimensions, but a graphical representation of the frontier is impossible to show for multiple outputs and inputs requiring graphs of four or more dimensions.

6. Performance is used interchangeably with efficiency. In this thesis performance refers to A-10 availability measures of mission capable time, flying hours, and sorties flown as they relate to resources such as availability of parts and labor. Performance is the measure of the output of a system and the efficiency of the process through which that output was obtained (12).

7. Production Function is a mathematical concept used in economics that relates output to inputs in an equation. For a production function

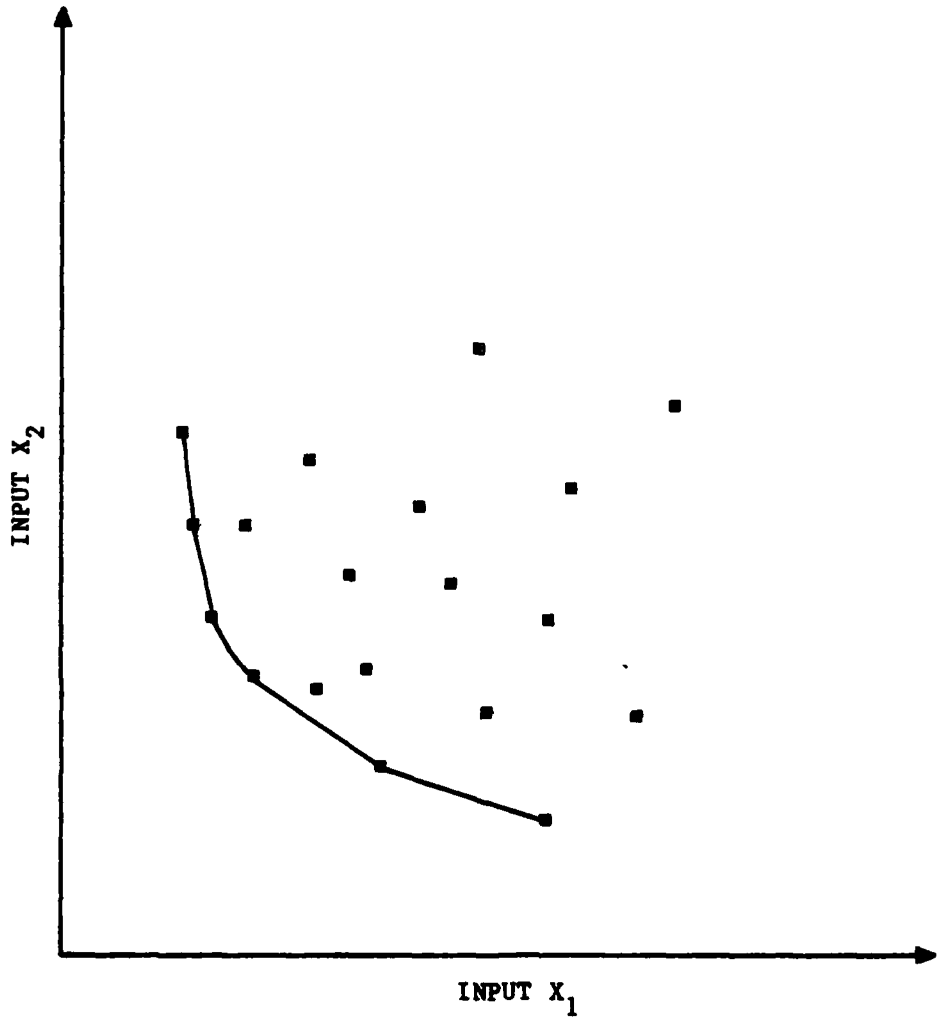

Figure 1. Frontier Concept

to be useful for performance evaluation, the mathematical relationship between outputs and inputs must be specified. A general form for a single output production function is $y = f(x_1, x_2, x_3 \ldots x_n)$, which, stated in words, means that output y is a function of the vector of multiple inputs $(x_1, x_2, x_3 \ldots x_n)$ (12).

8. Relative Efficiency Performance: The Constrained Facet Analysis model empirically measures the performance of a given unit relative to the performance of other units. It is not an absolute standard. For this thesis, the performance, or efficiency, of any A-10 aircraft or unit is measured relative to the other A-10 aircraft and units in the study.

Background

Performance evaluation is required to obtain important feedback on system efficiency for management decision making. So the reader will be better able to understand the need for and importance of performance evaluation in management, this section further expands the definition of performance. Discussions of why and how performance is evaluated are also included, along with a discussion of the reasons for understanding this research.

The A-10 Performance System. Performance is the conversion of inputs into outputs by a specific system. This conversion can be expressed as a ratio (17:323):

$$\text{Performance} = \frac{\text{Outputs Achieved}}{\text{Inputs Provided}}$$

From the above equation, we see that changes in any factor of input or output will affect the overall performance of the system. Performance could be improved by reducing inputs or augmenting outputs. It is also affected by the process that converts inputs into outputs. For this thesis, A-10 aircraft and AMUs, and the inputs and outputs identified for each, represent performance systems. The management, mission, location, and time period are environmental factors that affect the performance of the systems. Performance evaluation is important because it provides the feedback necessary to control and monitor these systems. The A-10 systems described above are shown pictorially in Figure 2. This figure serves as the framework for the rest of this thesis. A more in-depth discussion of how this system is adopted to the CFA model is discussed in Chapter II.

Performance Evaluation: Why? Performance evaluation provides important feedback for the managerial activities of controlling, directing, and planning system operations and improvements. Performance evaluation should be a factor in good decision making in any organization and is applicable to all managers, military as well as civilian. It helps managers make better decisions by giving them information concerning the function and efficiency of their organizations. Therefore, organizations evaluate performance as a basis for making improvements through effective decision making. The feedback generated by performance evaluation is an invaluable aid in setting realistic production goals (17:323). Performance evaluation also contributes to decisions involving resource allocation. Still another use for performance evaluation involves operational planning. In this study, planning decisions regarding capability and mission

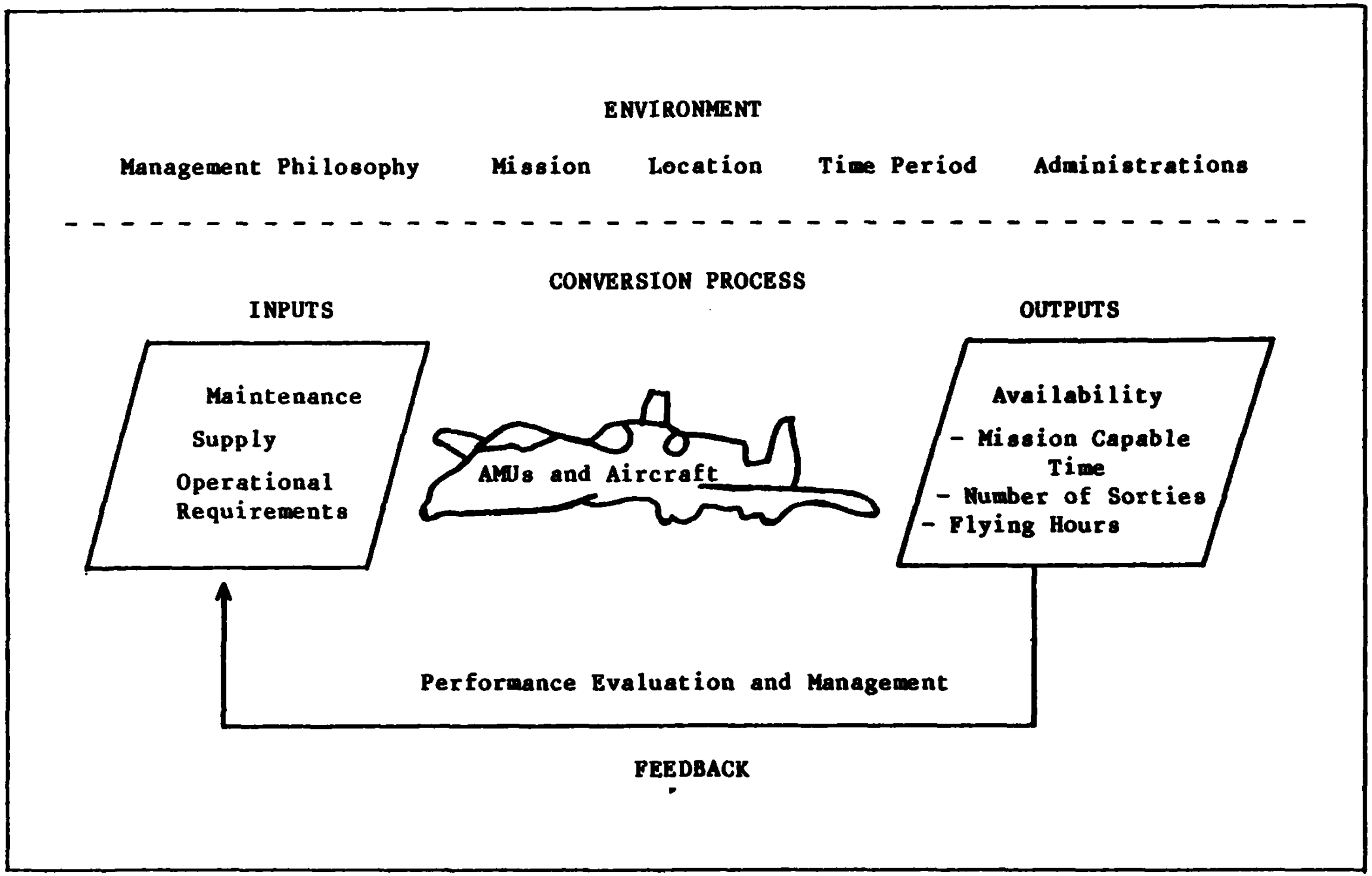

Figure 2. A-10 AMU or Aircraft Performance System

are made using information which includes performance. Performance evaluation is an essential part of all the aforementioned management situations because it supports and enhances decision making.

The study of performance applies to military managers for three major reasons. First, the military is subject to close scrutiny by the public because the military spends a large portion of the federal budget and must justify the use of those funds. Military managers must operate in a responsible and efficient manner. In the past year, numerous reports revealed the exorbitant cost of procurement and upkeep of military weapon systems. Reform is mandated and can be best achieved through performance evaluations which bring about improvements in efficiency (13:12-30).

Performance evaluation is also important to the Air Force because of the impact it has on private industry through defense contracts. Maintaining efficient weapon systems can be achieved by the military working in concert with the defense industrial base. Efficiency programs in both the military and the defense industry will improve weapon system reliability and combat performance, as well as provide profit and growth incentive for contractors (15:50). The combined effect of these two forces will help strengthen the economy of the United States.

Lastly, the Air Force must balance efficiency with effectiveness. The Air Force, as a defense service for the United States, must never be forced to compromise readiness and mission accomplishment. The successful Air Force managers will be those who understand what performance evaluation is and how to use it in monitoring, controlling, and improving military capability.

<u>Performance</u> <u>Evaluation:</u> <u>How</u>? There are many performance evaluation techniques available to the manager. Selection from among the various techniques depends on the system under study and the depth of examination desired. The techniques that will be discussed in this report include surveys, ratios, regression analysis, and Constrained Facet Analysis. All measures of performance, their differences and their applicability will be discussed.

Perhaps the least quantitative method of performance evaluation is the survey. This method can give the manager some idea of how workers and managers view performance, and it is a useful starting point if differences between the two are extreme (15:58). Surveys can be brief in scope and time period, or more complex. For example, a survey could be the result of a few interviews or could be an in-depth survey using written questionnaires with a statistical analysis of results.

Ratio analysis is a very popular and common form of performance measurement that managers can understand and use. Air Force examples of the use of ratios are maintenance manhours per flying hour and percent fill ratios such as assigned/authorized skill levels. The problem with ratio measures is that they often relate only one input to one output at a time. When the number of inputs and outputs of a system is large, the number of ratios that can be derived is staggering. For example, if there are 4 outputs and 10 inputs of interest to management, there are 4 times 10, or 40, possible output and input ratios that can be formed. Even experienced managers will have difficulty sorting out the important measures and using them for effective decision making. It is difficult for humans to recognize the multiple interactions among a large number of ratios using cognitive skills alone. Even ratios which relate multiple inputs to multiple outputs are difficult to interpret because the relationships between individual inputs and outputs may not be apparent.

Regression analysis is another commonly used performance measurement technique that measures several inputs against one output. Regression analysis determines mathematical relationships between the inputs of a system and its output. In this way, the manager can see what inputs affect the output. However, even multiple regressions cannot deal with situations where multiple outputs and inputs must be considered simultaneously. Also, since regression requires a priori specification of the form of the production function, this method is not useful for evaluating not-for-profit organizations. Production functions for not-for-profit organizations are very difficult to determine (6).

Constrained Facet Analysis (CFA) overcomes the problems encountered in the ratio and regression analysis methods of performance evaluation. CFA can provide one performance rating for multiple input and output situations. CFA evaluates relative performance of systems under study by building a frontier of efficiency (7:4). An in-depth description of the mechanics of CFA is included in Chapter II.

Evolution of Research. This thesis grew out of the author's interest in aircraft maintenance and in performance evaluation as a way of improving maintenance management. It is this author's impression that many areas of maintenance deserve attention and need improvement. It is also evident that many improvements and innovations are within the grasp of wing maintenance managers. Performance evaluation contributes to improvement because it identifies efficiencies and inefficiencies and provides a basis from which to manage.

The intention in this thesis was not to study a particular unit but rather to show one way of evaluating a maintenance organization. Further, this research sought to show that the method of evaluation, CFA, can give relatively quick results useful at all maintenance management levels.

Discussion of this thesis with Lt Col Clark, AFIT/LSM at Wright-Patterson AFB OH, led to the selection of the CFA methodology due to its appropriateness for performance evaluation of multiple input, multiple output maintenance units. Detailed reasons for the selection of CFA are discussed in Chapter II.

Research Objectives

1. The primary research objective is to provide a logical and useful evaluation of A-10 maintenance units and aircraft using the CFA model.

2. The author also hopes to show that aircraft evaluation can be used to evaluate unit performance.

3. Another major objective is to demonstrate the usefulness of the CFA model as an Air Force performance evaluation technique. Use of the CFA model expands the manager's repertoire of decision making

tools by providing an effective means of obtaining relative measures of performance, productivity, or efficiency.

4. To communicate the results of the above objectives, it is necessary to evaluate CFA data and translate it into usable management information. Presenting results clearly is also an objective of this research.

Research Questions

Several research questions directed this research:

1. What are the relative efficiencies of AMUs and aircraft in the wing studied?
2. Can aircraft performance be used as a basis for unit or wing evaluation?
3. Did CFA provide a reasonable and adequate evaluation for this thesis?
4. Could the CFA results be communicated to, and used by, Air Force maintenance managers?

II. Methodology

Introduction

This chapter discusses the Constrained Facet Analysis (CFA) model and how it applies to performance evaluation of A-10 AMUs and aircraft. The development of CFA and its usefulness will be presented, along with the particular mechanics of the model that apply to this thesis. Also included is a discussion of the data collected and used in this research.

Research Model

History. Constrained Facet Analysis was developed by Lt Col Clark (11) in the early 1980s as a method of performance evaluation and decision support. CFA is a direct outgrowth of Data Envelopment Analysis (DEA) which was developed by Charnes, Cooper, and Rhodes in the late 1970s (10). These analysis models represent breakthroughs in the performance evaluation field because they are the first to deal with multiple outputs as well as multiple inputs. Further, CFA and DEA are especially suited to nonprofit organizations because, unlike regression analysis, they do not require a priori specification of mathematical production functions (6).

CFA and DEA have been tested in many nonprofit organizations. Bessent, Bessent, Kennington, and Reagan performed a DEA analysis of the Houston Independent School System in 1979 (6). These researchers were able to screen schools and separate the efficient schools from the inefficient ones. More importantly, they were able to provide managers with empirically based information for goal setting, resource allocation, and operational planning. The empirical nature of the data and the objectivity of the results are features of DEA and CFA that make them desirable performance evaluation techniques.

DEA has been used with success in many areas of research. It has been used to evaluate performance in hospitals, military recruitment, and in the court system (4:28-32). In each case, DEA provided a performance evaluation of the organizations that identified efficiencies and inefficiencies. There appears to be an ever increasing range of applicability for DEA and the new capabilities of CFA.

Lt Col Clark was the first to demonstrate the use of CFA in evaluating Air Force units in 1983. His study used Air Force wings as Decision Making Units (DMUs) and determined efficient and inefficient units based on their use of inputs and their production of outputs (11). Further, the research cited several reasons for using CFA to assess military performance, including the need to consider multiple inputs and multiple outputs simultaneously, the need to have access to information on input mixes, and the difficulty in determining and quantifying production functions for military units (1:166-167). Clark's study included a thorough review of the DEA model, and the theory he developed overcame many of the limitations of DEA with respect to rating efficiency of outlier units (11:171). This research will demonstrate the use of the CFA model in another military context.

Constrained Facet Analysis (CFA) Model. CFA is a linear fractional program that calculates a relative efficiency for each unit under study (4:10). The objective function that refers to unit efficiency in the CFA model is evaluated subject to constraints that are derived from the input and output mixes for each unit. Those interested in the formulation of the CFA program should review the works of Clark and the Bessents (7; 8; 11). CFA is an extension of DEA and the first iteration of CFA is equivalent to DEA. CFA differs from DEA in that outlier units are subjected to an iterative analysis procedure which expands the set of frontier units used as a standard for measuring the efficiency of each unit, and which establishes a lower bound of efficiency for these inefficient outlier units.

Managers can use these models without understanding the mathematical forms; however, there are basic concepts that must be grasped to use the models for performance evaluations. First, it must be stressed again that CFA determines relative efficiency and not an absolute standard. The efficiency is reported on a scale from zero to one. Units rated one are efficient relative to others and those rated less than one are inefficient. Use of these measures is discussed in detail in Chapter III.

Second, managers should also be aware that CFA provides production rates, substitution rates, and values if efficient. From these values managers can determine what changes could be made in input and output quantities to improve efficiency.

Finally, CFA also indicates which frontier units were used to establish the efficiency rating of a unit. It also shows which frontier unit most closely resembles the inefficient unit in input and output mix. This concept and others will be clarified in Chapter III.

Summary of Why CFA Was Selected. The CFA model is aptly suited to the analysis of A-10 AMU and aircraft performance. A review of the reasons why CFA is applicable to the research includes:

1. The model deals with multiple inputs and multiple outputs simultaneously.
2. CFA does not require a priori specification of the production function and is therefore appropriate for evaluation of not-for-profit organizations.
3. Empirical data is used in the analysis of performance using CFA.
4. CFA computes the relative efficiency of the units under study and therefore does not require absolute standards of maximum performance which usually are not available.
5. Further, CFA is an objective mathematical analysis of performance.
6. The CFA computer program has already been developed and is available for use by Air Force Institute of Technology (AFIT) students through the University of Texas at Austin.

Selection of the Decision Making Unit (DMU)

Decision making unit (DMU) selection is a very important step in a CFA analysis. DMUs are the specific organizational units to be evaluated and identify the system being studied (see Figure 2). The DMUs for this analysis were A-10 AMUs and aircraft. The performance of an A-10 AMU or an aircraft, whether efficient or inefficient, was determined by the CFA program in terms of the level of output an AMU or aircraft achieved with its levels of inputs. DMU selection was a critical step in this study of performance because it influences the selection of inputs and outputs.

The first evaluation was done with AMUs as DMUs. AMUs were used for several reasons. In general, AMUs are homogeneous; that is, they will all have similar inputs and outputs. A major concern was the availability of data; this author found empirical data was available for the evaluation of AMUs. A final reason for selecting AMU as the unit of evaluation was that AMUs are closely monitored by management and are already subject to performance evaluations other than CFA.

In the second evaluation, individual aircraft were selected as DMUs for several reasons. First, the choice of aircraft provided a large set of observations, which is consistent with the requirements of CFA and DEA (4:13). Also, aircraft represent a homogeneous group of units. Thus, we can assume that all aircraft draw on similar resources and produce the same categories of outputs. This avoids the problem of selecting inputs and outputs that are not common to all DMUs and insures comparability.

From a conceptual standpoint, evaluations of aircraft performance provide useful information for evaluating AMU performance without the complications involved in studying the larger units. The measures of aircraft performance can be aggregated to obtain measures of AMU or wing performance. This aggregation provides a measure of wing performance which takes into account aircraft availability and the wings flying mission.

Both evaluations of AMUs and evaluations of aircraft were accomplished to show the flexibility of the CFA model. Also, these analyses produced results that Air Force managers can understand. CFA gives the information necessary to compute ratio measures such as sortie rate and mission capable rate which are familiar to managers. For example, ratio measures can be computed for an inefficient unit from the empirical data provided. After the CFA analysis, ratios representing efficient operations could also be determined for the same inefficient unit by computing the ratios from the values if efficient which are provided by the model (8:149). This gives managers targets that they can understand and use to improve efficiency, targets that are based on the unit's present condition and capabilities. Examples of this type of conversion of data will be important in the analysis of results and in the presentation of results to managers.

The selection of DMUs was done prior to the selection of input and output measures. The next section deals with the selection of input and output measures as they applied to the DMUs for this research.

Input/Output Measures

General Selection Criteria. An important element of the CFA method is the selection of input and output measures. Although the input and output measures for AMU and aircraft analysis differ somewhat, the general criteria for their selection are the same. These criteria include:

1. The measures should be complete enough to measure key goals (outputs) and required resources (inputs) of the DMU being evaluated (5:3).
2. The relationship between inputs and outputs is also an important consideration. Inputs should be defined directionally; that is, when an input is increased, an increase in output is expected (6:1360).
3. It is important that all DMUs use some of each input to produce their outputs (4:16).
4. Even inputs that are not controllable by managers should be included (5:16).

The remainder of this section describes input and output measures for AMU evaluation followed by measures for aircraft evaluation.

AMU Output Measures.

Output 1: Number of sorties flown per time period. A sortie includes takeoff, flight, and full stop landing of an aircraft. For this thesis, the type of sortie (i.e., training, combat, deployment), was not differentiated; thus, all sorties were added together to yield a single sortie measure of output. In the AMU analysis, sorties were accrued on a monthly basis and represented all sorties on all AMU aircraft for a specified calendar month. Sorties were selected as an output measure because in a fighter wing the number of sorties generated are critical in assessing effectiveness and performance. Sorties represent a measurable and important AMU goal and were therefore included in the CFA analysis.

Output 2: Mission capable time per time period. Mission capable time for an AMU is the sum of all the mission capable time on each AMU aircraft. An aircraft is mission capable when it is available for flight or otherwise not engaged in flying but requiring no maintenance or supply parts. For this thesis, mission capable includes fully mission capable (FMC) and partially mission capable (PMC). The measures of mission capable time included in this research are monthly totals. A major readiness goal of AMUs is to maximize their mission capable time, and for this reason mission capable time is used as an output measure for the analysis.

AMU Input Measures.

Input 1: Number of aircraft possessed per time period. Each AMU has specific aircraft assigned. This author considered the number of aircraft each AMU had available for use to be an input measure. The number of aircraft possessed represents a monetary and equipment resource. Intuitively, one would expect the number of sorties and the amount of mission capable time to increase with an increase in the number of aircraft available.

Input 2: Reciprocal of Not Mission Capable Maintenance (RNMCM). Not mission capable maintenance is a measure of the time aircraft were unavailable for operations because maintenance was required or in progress to return the aircraft to mission capable status. In the source data for this thesis, not mission capable maintenance time was measured in hours per month and was the sum of all not mission capable maintenance time on all AMU aircraft. The reciprocal of NMCM was used as input data for the CFA model to preserve directionality. One would expect outputs to increase as the not mission capable time decreases or its reciprocal increases. The reciprocal of NMCM is a surrogate measure of maintenance capability.

Input 3: Reciprocal of Not Mission Capable Supply (RNMCS). Not mission capable supply is a measure of the time an aircraft was unavailable due to lack of supply parts. It was treated in the same manner as NMCM time. The reciprocal of NMCS is a surrogate measure of the supply support provided to an AMU.

Input 4: Number of flying days per time period. A flying day is a calendar day for which flying was scheduled and accomplished. The number of flying days per month was used as an input measure for the AMU because it measures the availability of time used to achieve outputs. It was expected that as the number of flying days increased, sorties and mission capable time would also increase, thus meeting the directionality criterion for inputs.

Input 5: Fix rate per time period. The fix rate is the percentage of code 3 aircraft malfunctions in a month which are repaired within eight hours after the malfunction. A code 3 break refers to an aircraft malfunction discovered in flight which prohibits further flight of the aircraft until the malfunction is fixed. For this research the fix rate was obtained directly from source data. The fix rate is a surrogate measure of the quality, quantity, and management of resources, as a high fix rate indicates a good supply of resources or that resources are being managed well. A low fix rate could indicate shortfalls in manpower, training, supply, or management effectiveness.

Aircraft Output Measures.

Output 1: Number of sorties flown per time period. A sortie was defined in AMU output 1. In the aircraft analysis sorties represent the total weekly sorties per aircraft. Sorties can be considered outputs of each aircraft and were therefore included in the CFA analysis.

Output 2: Number of flying hours accrued per time period. Flying hours include the time an aircraft is flying and performing a mission. Flying hours are important because they are allotted to Air Force wings on an annual basis. This thesis treats the flying hours of each aircraft as an activity which contributes to the overall wing flying hour program. Flying hours were estimated per aircraft per week for this research.

Output 3: Number of mission capable hours accrued per time period. The concept of mission capable was defined in AMU output 2. Aircraft undergoing maintenance of any kind, including inspection and washes, or needing parts for flight are not considered mission capable. Maintaining a pool of mission capable aircraft is a key goal of a wing. For this analysis, mission capable was also considered to be a goal of individual aircraft and was estimated on a weekly basis for each aircraft.

Aircraft Input Measures.

Input 1: Mean Time Before Failure (MTBF) per time period. The MTBF is a measure of reliability that is inherent in each aircraft. One would expect that the greater the MTBF, the greater mission capable time would be. Because the aircraft data was simulated, the MTBF is an estimate. This simulation will be discussed in the aircraft data section.

Input 2: Reciprocal of Not Mission Capable Maintenance (RNMCM) per time period. The reciprocal of NMCM was used as an input measure for aircraft for the same reasons it was used in the AMU analysis. The differences in using this measure for aircraft was that NMCM was estimated for each aircraft for a one week time period.

Input 3: Reciprocal of Not Mission Capable Supply (NMCS) per time period. This input is similar to that used in the AMU analysis. As in input 2 (1/NMCM) for aircraft, it was estimated for each aircraft for one week.

Input 4: Number of sorties scheduled per time period. The number of sorties scheduled was used as an input because of its effect on the number of sorties an aircraft flew. An increase in the number of sorties scheduled for an aircraft should increase the number of sorties that will be flown by that aircraft. The ratio of sorties flown to sorties scheduled shows how much aircraft are falling short of their sortie commitments.

Input 5: Manhours per flying hour per time period. Manhours per flying hour is a measure of the maintenance time required to produce each flying hour. It was used as a surrogate input measure of manpower applied, inherent aircraft reliability and maintainability. It was expected that an increase in this input would relate to an increase in outputs. In this analysis manhours per flying hour ratios were estimated based on data from a time period of one week.

Data

This section addresses the data used in the CFA analysis for this thesis. Discussion begins with AMU data followed by aircraft data. The section concludes with a summary of data collection and use of the CFA program.

AMU Data. The source data for the AMU analysis was obtained from the 354th Tactical Fighter Wing at Myrtle Beach AFB, Myrtle Beach, South Carolina. The source documents for this data were the 354th's monthly maintenance data analysis reports (16). Five months of data, from October 1983 to February 1984, were used to compare efficiency for three AMUs, the 353rd, 355th, and 356th.

The desired input and output measures were obtained directly from the source data and used as input data for the CFA program. The reciprocals for NMCM and NMCS were calculated and scaled by 1×10^6 for ease of computation. Table I shows the data set used for the CFA evaluation of AMUs.

Aircraft Data. The data set for aircraft evaluation was simulated and was not empirical. The simulation was based on the empirical data used in the AMU analysis; however, no real aircraft were represented. For each output and input measure, a range was determined based on available AMU data. This range was scaled to estimate individual aircraft for a weekly time period. Extreme values (see aircraft numbers 10, 11, 27, and 28) were included in the data set to represent hangar queens[1] and high flyers.[2]

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[1] A hangar queen is the maintenance term used to denote an aircraft that has been grounded for several days due to severe maintenance or supply problems.

[2] A high flyer is an aircraft that performs above average in terms of number of sorties and flying time.

TABLE I

Aircraft Maintenance Unit Analysis Data

		OUTPUTS		INPUTS				
	AMU	Number of Sorties	Number of MC Hours	Number of Aircraft	Reciprocal of NMCM*	Reciprocal of NMCS*	Number of Flying Days	Fix Rate**
1	353 Oct 84	595	17607.0	26.9	677.9	975.3	19	91.4
2	355 Oct 84	563	17299.7	26.8	650.8	1079.7	19	87.3
3	356 Oct 84	582	18731.7	27.6	900.6	2257.3	19	90.6
4	353 Nov 84	649	15732.2	24.6	631.6	1893.6	20	76.1
5	355 Nov 84	665	15208.6	24.4	558.4	1251.9	20	88.2
6	356 Nov 84	710	18208.5	28.9	506.9	1609.0	20	75.4
7	353 Dec 84	423	16481.3	24.2	843.2	1644.2	21	87.2
8	355 Dec 84	446	17327.8	26.0	584.0	1417.2	21	86.2
9	356 Dec 84	367	19032.8	28.1	818.1	693.1	21	81.6
10	353 Jan 84	489	16329.7	25.7	536.7	1338.0	21	85.5
11	355 Jan 84	516	16244.5	25.0	454.0	988.2	21	95.3
12	356 Jan 84	514	18163.6	28.2	482.2	1099.0	21	82.0
13	353 Feb 84	449	16476.3	25.5	880.5	17667.8***	20	88.9
14	355 Feb 84	434	13783.6	23.3	537.3	1702.7	21	78.9
15	356 Feb 84	432	14202.5	23.5	922.5	1052.6	21	85.7

Note: All data per month (16)

* Scaled by 1,000,000
** Based on 8 hour periods
*** Suspected error in source data

An example of how aircraft values were estimated for mission capable hours is shown below.

1. From 354TFW data the number of mission capable hours was divided by the number of aircraft for each month. Each of these numbers was then divided by four to give the average number of mission capable hours per aircraft per week:

$$\text{October} = \frac{53639.4 \text{ Mission Capable Hours/Month}}{80.1 \text{ Aircraft} \times 4 \text{ Weeks/Month}}$$

$$= 167.4 \text{ Mission Capable Hours/Aircraft/Week}$$

$$\text{November} = \frac{49149.3 \text{ Mission Capable Hours/Month}}{77.5 \text{ Aircraft} \times 4 \text{ Weeks/Month}}$$

$$= 158.5 \text{ Mission Capable Hours/Aircraft/Week}$$

$$\text{December} = \frac{52841.9 \text{ Mission Capable Hours/Month}}{79.7 \text{ Aircraft} \times 4 \text{ Weeks/Month}}$$

$$= 165.8 \text{ Mission Capable Hours/Aircraft/Week}$$

$$\text{January} = \frac{50737.8 \text{ Mission Capable Hours/Month}}{78.5 \text{ Aircraft} \times 4 \text{ Weeks/Month}}$$

$$= 161.6 \text{ Mission Capable Hours/Aircraft/Week}$$

$$\text{February} = \frac{44462.4 \text{ Mission Capable Hours/Month}}{71.6 \text{ Aircraft} \times 4 \text{ Weeks/Month}}$$

$$= 155.2 \text{ Mission Capable Hours/Aircraft/Week}$$

2. The average of the above was used as the average mission capable hours per aircraft per week:

$$\frac{167.4 + 158.5 + 165.8 + 161.6 + 155.2}{5} = 161.7$$

3. The average (161.7) was used as a base to create mission capable hours for 28 aircraft (see Table II). For aircraft numbers 10 and 11 very low mission capable hours were used because these aircraft were intended to represent hangar queens. Aircraft 14 and 15 have low mission capable hours to represent aircraft that have relatively average inputs but still perform below average in mission capable time due to poor management, inherent reliability of the aircraft, or other problems.

All output and input measures were created in a similar fashion: an average was obtained from empirical data and a realistic range was created. Extreme values were used to indicate special cases such as hangar queens or high flyers.

Data Collection and Computer Use. The primary source of data for this thesis was the 354 Tactical Fighter Wing at Myrtle Beach AFB. The data was provided by a wing maintenance officer and arrived in the form of monthly data analysis reports and Quality Assurance reports (16). This author found that the typical wing data analysis reports gave many input and output measures required for CFA analysis. These reports also highlighted the need for an evaluation such as CFA because they merely list or display tables of measures. They do not relate inputs to performance outputs nor do they attempt to compare unit performances via single measures of efficiency.

Two other sources of data were sought but found of little use in this study. Air Force Logistics Command (AFLC) supplied several computer tapes of discrepancies on A-10 aircraft. This data could not

TABLE II

Aircraft Analysis Data

AFCT	OUTPUTS: No. of Sorties Flown	No. of Flying Hours	No. of MC Hours	INPUTS: MTBF *	RNMCM **	RNMCS **	No. of Sorties Scheduled	MH/FH
1	18	28.8	167	8	50	170	18	32
2	19	30.4	166	8	85	200	19	33
3	20	32.0	165	9	65	160	20	34
4	21	33.6	164	9	60	170	21	32
5	22	35.2	163	10	45	180	22	33
6	23	26.8	162	10	70	250	22	34
7	24	38.4	161	11	80	200	23	37
8	25	40.0	160	11	75	190	25	36
9	26	41.6	159	11	90	200	25	35
10	2	2.0	20	6	40	70	2	120
11	5	7.0	40	5	35	80	5	120
12	10	16.0	130	6	80	150	12	50
13	11	17.6	131	6	70	140	12	49
14	12	17.6	129	5	65	130	13	48
15	13	20.8	128	5	60	200	13	50
16	14	20.8	70	8	70	160	15	49
17	15	24.0	80	8	80	90	15	48
18	18	27.2	155	10	60	90	18	36
19	19	32.0	154	10	65	90	19	35
20	20	30.0	153	11	50	150	21	34
21	21	32.0	152	11	55	160	21	34
22	22	30.0	151	12	45	200	21	35
23	23	35.0	150	13	40	190	22	36
24	24	36.2	149	14	35	180	24	37
25	25	37.0	148	14	30	200	25	38
26	26	38.5	146	14	50	140	25	37
27	30	48.0	150	15	60	200	30	32
28	31	49.6	139	16	70	250	30	38

* Mean Time Before Failure (operational hours/number of failures)
** Scaled by 100,000

MH/FH = Manhours per flying hour
RNMCM = Reciprocal of not mission capable maintenance
RNMCS = Reciprocal of not mission capable supply
AFCT = Aircraft

be used because input and output measures were not identified or related to specific time periods. Future studies using CFA may find some information available through AFLC, but they must be careful to obtain data suitable for CFA. Tactical Air Command (TAC) supplied A-10 AMU and wing data for all CONUS A-10 bases. This data arrived too late for this thesis but is available for future studies.

Data was extracted from the maintenance reports and collated for each analysis (see Tables I and II). This data was typed directly into a data file at the University of Texas at Austin and used in their CFA program. The specific file requirements are available through Lt Col Clark at the Air Force Institute of Technology (AFIT) or from the Educational Productivity Council, Department of Educational Administration, University of Texas at Austin (8:6). For large data sets, researchers are advised to prepare files on punch cards in advance of using the University's CFA program.

CFA and DEA programs were run on each data set, AMU and aircraft, at the University of Texas on 25 and 26 June 1984. This researcher found the CDC Cyber at the University of Texas relatively easy to access and the CFA and DEA programs easy to use, giving rapid results.

DEA was exercised as an additional analysis because it was available at the time the CFA analysis was performed, and DEA was able to use the same data sets. The DEA program provides the upper bound efficiency measures of CFA; results of both analyses are given in Chapter III. The major intent of the thesis remained the same -- to show CFA applicability to maintenance management. CFA analysis alone proved to be sufficient for the objectives of this research.

III. Findings and Analysis

Introduction

This chapter includes results and a discussion of those results for AMU and aircraft analyses. The chapter is divided into two major sections, one on AMUs and one on aircraft. Each section includes findings for CFA and DEA analyses. Additionally, the AMU section includes a correlation analysis of input and output measures.

In both the AMU and aircraft analyses, several output options were analyzed by the CFA program. Each section includes computer analyses of each data set using all outputs and an analysis using each output alone. In all cases, all input measures were included. This will be discussed in greater detail in each section.

Aircraft Maintenance Unit (AMU) Analysis

Phase 1: Efficiency Ratings. The primary result of the CFA analysis was the upper and lower bound efficiency ratings obtained for each AMU in the study (see Table III).[3] Of the 15 AMU evaluations, six were rated as inefficient relative the others. Closer examination showed that the 353rd AMU was inefficient three times, the 355th AMU was rated inefficient twice, and the 356th AMU was rated inefficient

[3]Table III also contains output shortage amounts and input surplus amounts which will be used later in this chapter in computing "values if efficient."

TABLE III

CFA Results for AMU Analysis Using Two Outputs

DMU	EFFICIENCY LB	EFFICIENCY UB	OUTPUT SHORTAGES OUTPUT 1	OUTPUT SHORTAGES OUTPUT 2	INPUT SURPLUSES INPUT 1	INPUT SURPLUSES INPUT 2	INPUT SURPLUSES INPUT 3	INPUT SURPLUSES INPUT 4	INPUT SURPLUSES INPUT 5
1	1.00000	1.00000							
2	1.00000	1.00000							
3	1.00000	1.00000							
4	1.00000	1.00000							
5	1.00000	1.00000							
6	1.00000	1.00000							
7	.90146	.99227	39.374	0	0	665.784	0	3.745	9.129
8	.95989	.99292	59.779	0	0	0	24.736	1.607	5.571
9	1.00000	1.00000							
10	.93508	.99194	0	0	0	0	209.094	2.527	7.773
11	1.00000	1.00000							
12	1.00000	1.00000							
13	.90002	.95494	21.108	0	0	66.748	0	2.071	7.152
14	.81411	.90167	0	0	0	0	665.329	3.628	3.423
15	.79550	.91643	0	0	0	276.699	0	3.826	8.881

UB = Upper Bound
LB = Lower Bound

only once. The apparent efficiencies and inefficiencies of these AMUs are summarized in Figure 3.

The relative efficiencies and inefficiencies that resulted from the analysis can also be viewed seasonally. All inefficiencies occurred in the December through February time periods. February appeared to be a particularly "bad" month for the AMUs, as all three were rated inefficient and received the lowest of the inefficient ratings in this month. The apparent seasonal effect on efficiency is portrayed in Figure 4.

Figure 4 may also be used to make inferences regarding AMU stability as it relates to the performance parameters outlined in this research. Care must be taken in this area because a longer time span would probably give a better representation of stability. However, from the efficiency rating observed in the five month period represented, one notes that the 356th AMU appeared to be the most stable performer. The 353rd AMU also appears to have a degree of stability, although AMU's performance gradually deteriorated. In contrast, the 355th AMU appeared to be unstable by having more pronounced fluctuations in performance ratings.

Thus, from a simple comparison of efficiency measures, a manager can obtain useful feedback on unit performance. First, a manager can look at the efficiency measures and see what units are performing poorly relative to the others. Secondly, the efficiency measures can be compared to time changes, in this case months, to see if there are seasonal effects on performance. Lastly, the efficiency versus time

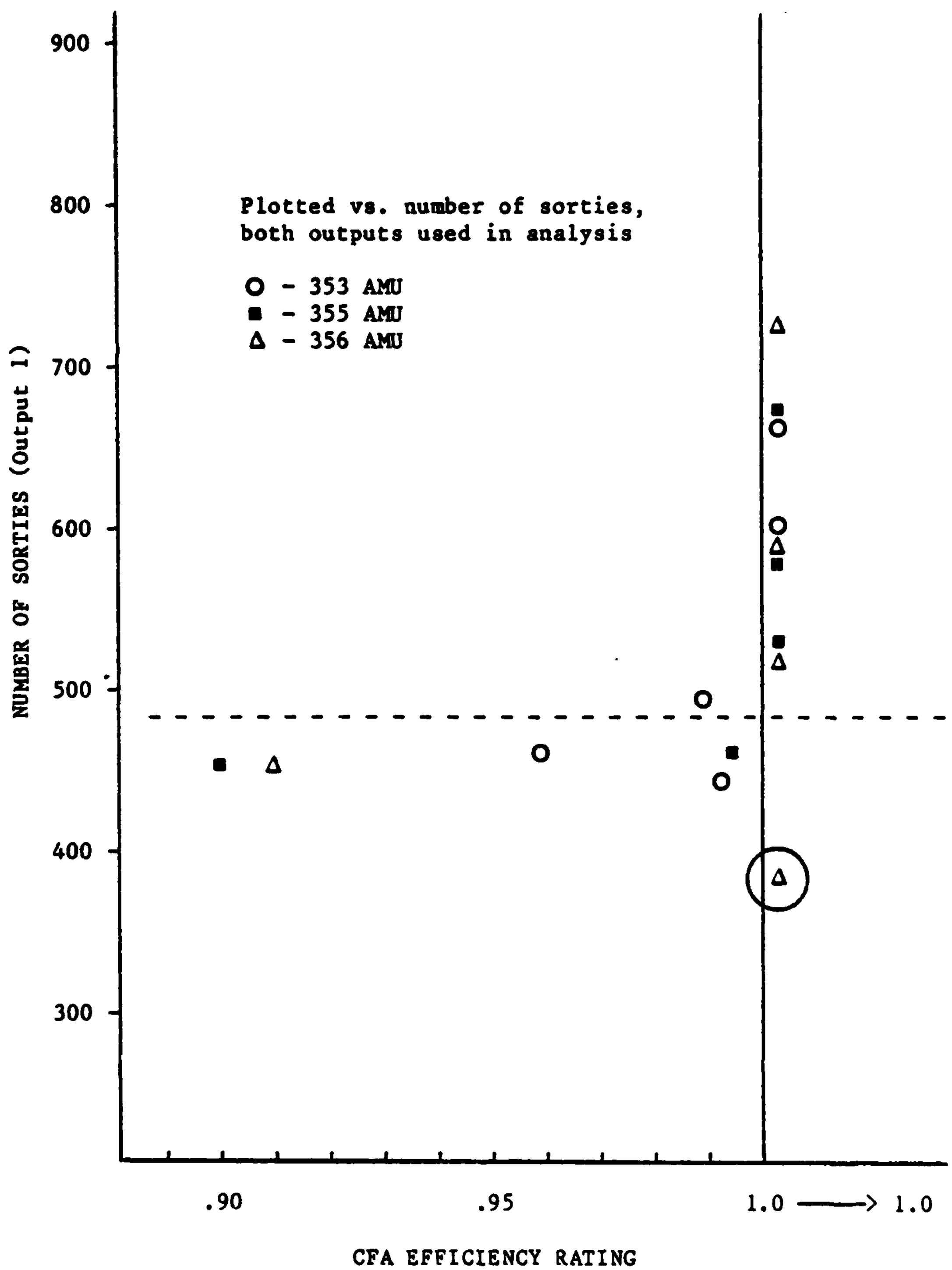

Figure 3. Relative Efficiencies of AMUs

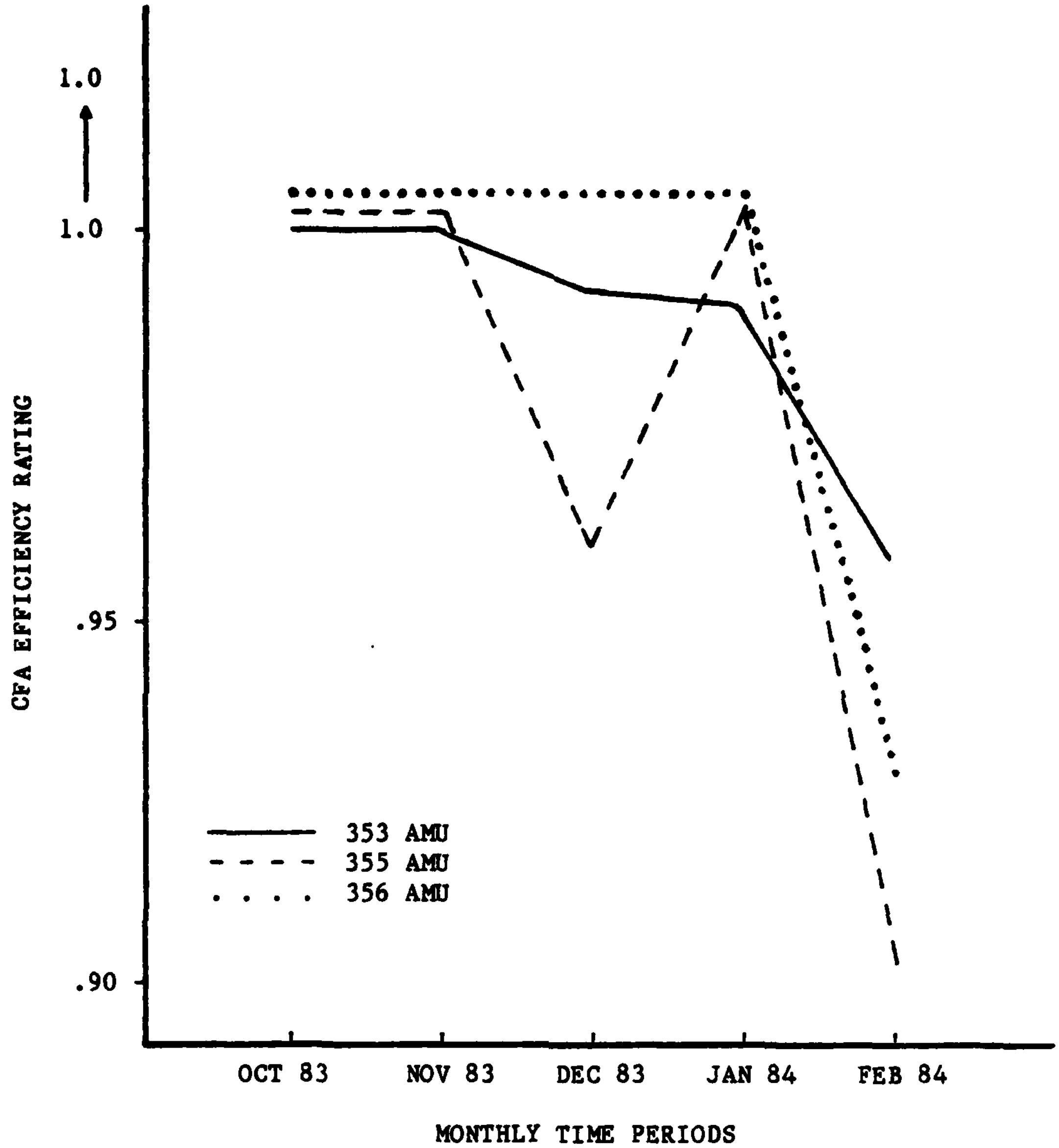

Figure 4. Seasonal Changes in Efficiency of 354 TFW AMUs

analysis can be used to give the manager a rough feel for unit stability and how units compare over time.

Efficiency/Effectiveness Comparison. The use of the efficiency ratings can be taken a step further to obtain some estimates of unit effectiveness. This can be attempted for output measures for which standards have already been set. In this thesis, two additional CFA runs were made using each output individually. The efficiency measures for each analysis were plotted versus their respective outputs. An output effectiveness level was obtained from the standards given in the source data.

The efficiency analysis using only the number of sorties as an output measure is summarized in Figure 5. The 354th Tactical Fighter Wing (TFW) apparently had a goal of approximately 480 sorties per month. This thesis used 480 as the standard per month; however, the reader should note that this goal could change with time, aircraft, and wings. The CFA analysis using only one output changed the efficiency ratings somewhat, but from it we can draw some basic conclusions that managers and analysts can use in all CFA analyses.

The first thing a manager will note after a basic comparison of efficiency ratings is whether the unit is above or below the performance goal. Figure 5 can be thought of as being divided into four quadrants. Quadrant I represents units that are efficient as well as effective. Clearly, all units in the analysis should have movement into quadrant I as a goal. Quadrant II represents units that are efficient but fall short of effectiveness. Units in this quadrant will find it difficult to move into quadrant I. It may be possible to force

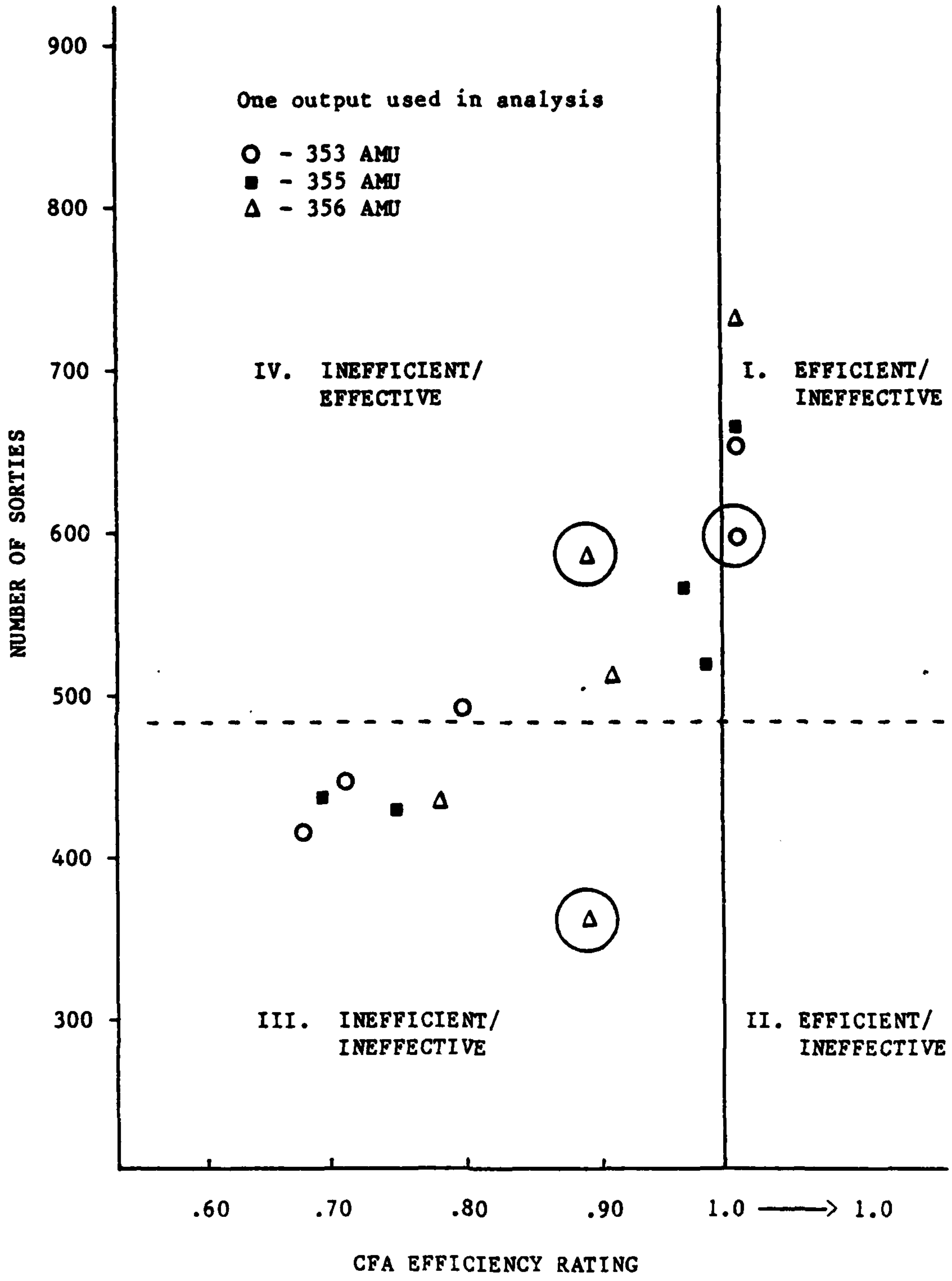

Figure 5. AMU Efficiency vs. Number of Sorties

the units in quadrant II to initially become inefficient by adding inputs and then become efficient by increasing outputs (18).

Units which are rated inefficient are represented by quadrants III and IV. The three circled units in Figure 5 highlight several key points. First, two units can have the same efficiency rating, yet have very different effectiveness levels. In contrast, two units can have similar effectiveness levels while having different efficiency ratings. The ability to analyze units in this way is one of the advantages of the CFA model, and the analysis was done fairly easily from the efficiency ratings.

When the sortie standard is applied to Figure 3, we see another useful result for management. Note that the circled unit in Figure 3 represents a unit that is efficient, yet its effectiveness in producing sorties is lower than all of the inefficient units. This means that this unit is using resources in the best way possible, but they are just not large enough to achieve greater output. For this unit to increase output, it will be necessary to increase inputs. In her study of schools, Linda Reaves (18) suggested that a strategem for moving units from the efficient/ineffective region into the efficient/effective region may be to increase the inputs for these units. She felt that perhaps this would force the units to become temporarily inefficient and move them into the inefficient/ineffective region. From there, she proposed these units could reach higher output levels and eventually move into the efficient/effective region. This type of management decision hinges upon the goal of organization. If output is the key goal, changes should be made in the input mix. However, if efficiency is a sufficient goal, the unit is achieving all that it needs to achieve.

Figure 6 shows a similar representation for analysis using mission capable hours as the comparison output. The standard for this analysis was obtained from source data which stated the goal for mission capable hours to be 85 percent of total hours. Total hours represent total hours per month on all aircraft. Thus, a standard of approximately 16,642 hours was obtained as follows:

(24 hours/day)(31 days/month)(26 aircraft/month/AMU) =
19,344 total hours/month/AMU

(19,344 total hours/month/AMU)(.85 MC hours/total hours) =
16,442.4 MC hours/month/AMU

Movement from quadrants III and IV to quadrant I can be accomplished in two ways -- input reduction or output augmentation, respectively. The CFA and DEA models provide the manager with information aimed at making these kinds of decisions. However, management must decide what level of performance is desired. If effectiveness is the sole criterion, an effective but inefficient unit may be acceptable. If we presume that inefficiencies, whether effective or not, need to be improved, then we can use CFA evaluation results as input for improvement decisions.

Phase 2: Values if Efficient. The next phase of analysis is to use the CFA and DEA "values if efficient." Using the efficiency ratings, output shortage amounts, and input surplus amounts from Table III, "values if efficient" can be computed for inefficient DMUs. It is important to note that all outputs and inputs must be adjusted

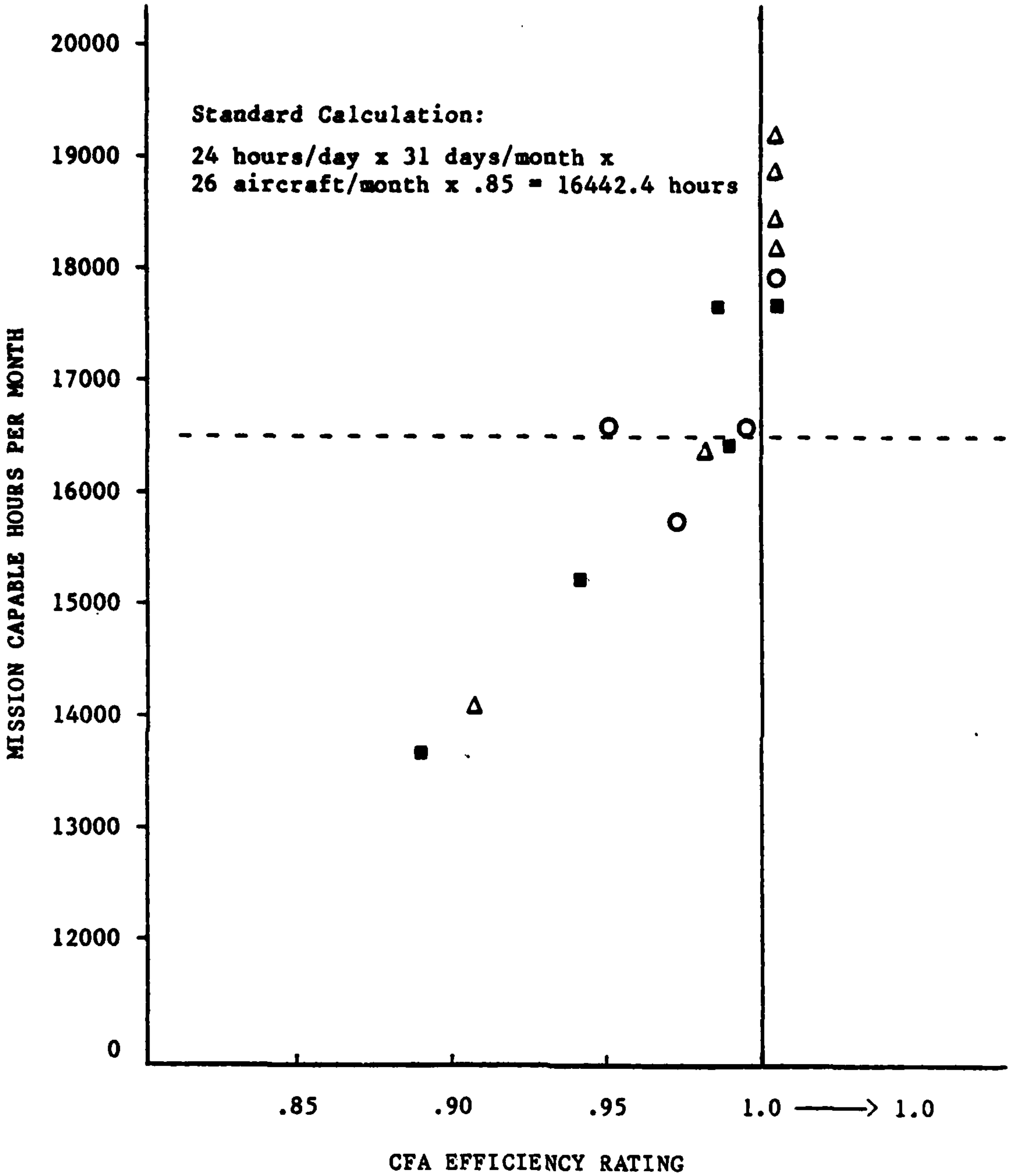

Figure 6. AMU Efficiency vs. Mission Capable Hours

for the unit to achieve an efficiency rating. Changing only a subset of the inputs or outputs will not result in an efficient rating.

For example, the "values if efficient" can be computed for Output 1 and Input 2 of DMU 7, which corresponds to the 353 AMU in December 1983, as follows: For Output 1, the computed shortage (39.37) from Table III is added to the observed value divided by the efficiency measure (423.0/.99227) which yields 465.7 as the "value if efficient" for Output 1, shown in Table IV. A "value if efficient" for Input 2 is calculated by subtracting the input surplus amount for Input 2 (67.78) from the observed value (843.2). The result is 775.4, which is the "value if efficient" for Input 2 as shown in Table IV. These calculations must be done for each input and output. This gives an input/output mix that would change the unit from an inefficient to an efficient rating.

The CFA/DEA programs provide computed "values if efficient" for managerial review and consideration. This feature helps make the results understandable and interpretable without requiring that managers be familiar with the mathematical complexities of the models.

The "values if efficient" for the analysis of AMUs using both outputs is shown in Table IV. The values if efficient for AMU 353 in December 83 will be used to show how managers can use this information to improve efficiency. First, the models determined that the number of sorties should increase from 423 to 465.7. This may not be possible because of weather or budget constraints, but some increase may be possible. A more manageable improvement might be made in mission capable hours to increase them from 16,481.3 to 16,611.3. This could

TABLE IV

Values if Efficient for AMU Analysis Using Two Outputs

AMU	EFFICIENCY RATING*	OBSERVED / VALUE IF EFFICIENT: OUTPUTS: Output 1	Output 2	INPUTS: Input 1	Input 2	Input 3	Input 4	Input 5
353 Dec 83	.99227	423.0/ 465.7	16481.3/ 16611.3	24.4/ 24.4	843.2/ 775.4	1644.2/ 1644.2	21.0/ 17.3	87.2/ 78.1
355 Dec 83	.99292	446.0/ 508.9	17327.8/ 17452.7	26.4/ 26.4	584.0/ 584.0	1417.2/ 1392.5	21.0/ 19.4	86.2/ 80.6
353 Jan 84	.99194	489.0/ 493.1	16329.7/ 16465.6	25.0/ 25.0	536.7/ 536.7	1338.0 1128.9	21.0/ 18.5	85.5/ 77.7
353 Jan 84	.95494	449.0/ 491.3	16476.3/ 16255.3	25.3/ 25.3	880.5/ 813.8	17667.8/ 17667.8	20.0/ 17.9	88.9/ 81.7
355 Feb 84	.90167	434.0/ 481.6	13783.6/ 15296.9	23.1/ 23.1	537.3/ 537.3	1702.7/ 1037.4	21.0/ 17.4	78.9/ 75.5
356 Feb 84	.91643	432.0/ 471.5	14202.5/ 15501.9	23.2/ 23.2	922.5/ 645.8	1052.6/ 1052.6	21.0/ 17.2	85.7/ 76.8

* Efficiency values are upper bound values from CFA

be accomplished through better management of maintenance personnel and time, improved debriefing and troubleshooting, or faster repairs.

The 353 AMU might also improve efficiency in December by reducing three of its inputs. Inputs 1 and 3 are not decreased by the model, but that does not restrict managers from implementing changes in these areas. Input 1, number of aircraft, is probably beyond the control of the AMU maintenance officer because the size of the organization is determined at higher command levels. Input 3, the reciprocal of not mission capable supply, is another input managers would probably not be able to directly affect at AMU level. The model shows reductions in the remaining three inputs, reciprocal of not mission capable maintenance, number of flying days, and fix rate. This means that if the observed level of outputs were obtained with the efficient levels of inputs, the unit would be rated efficient. In the military, however, it would be more advantageous for the unit to try to increase outputs rather than decrease inputs.

Phase 3: Management Ratios. The CFA/DEA "values if efficient" can also be converted into ratios that maintenance managers could more readily use and understand (11:148). For example, in the CFA analysis of 353 AMU in December 83 (Table IV), a sortie rate based on observed values could be calculated as follows:

$$\frac{\text{423 sorties/month}}{\text{24.4 aircraft}} = \text{17.3 sorties per month per aircraft}$$

Using the "value if efficient" for sorties, a new efficient sortie rate can be computed:

$$\frac{465.7 \text{ sorties/month}}{24.4 \text{ aircraft}} = 19.1 \text{ sorties per month per aircraft}$$

A similar conversion can be obtained for mission capable rate. Again using 353 AMU, December 83, the observed mission capable rate is:

$$\frac{16481.3 \text{ Mission Capable hours/month}}{24.4 \text{ aircraft} \times 31 \text{ days/month} \times 24 \text{ hours/day}} = 21.8/24 = .908$$

Similarly, an "if efficient" mission capable rate can be obtained using the "value if efficient" computed by CFA:

$$\frac{1611.3 \text{ Mission Capable hours/month}}{24.4 \text{ aircraft} \times 31 \text{ days/month} \times 24 \text{ hours/day}} = 22/24 = .916$$

Additional ratio conversions are possible. They are useful because maintenance managers are accustomed to managing with ratio measures and output rates.

Comparison of Multiple and Single Output Analysis. Three CFA analyses were tried for the AMU data. These trials included an analysis using both outputs simultaneously, followed by two analyses, each of which used only one output. A comparison of the efficiency ratings is shown in Table V. It is evident that the selection of output(s) can dramatically change the CFA efficiency ratings. Inclusion of both outputs gives a better portrait of overall efficiency.

Correlation. To test the relationships of outputs and inputs, a Pearson correlation analysis was performed using computer programs at the University of Texas. The AMU data set used in the CFA analyses was used for the correlation analysis. Results of the correlation are given in Table VI.

TABLE V

Comparison of Efficiency Ratings for AMU Analysis

	BOTH OUTPUTS		SINGLE OUTPUT = SORTIES		SINGLE OUTPUT = MISSION CAPABLE HOURS	
AMU*	LB	UB	LB	UB	LB	UB
1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2	1.00000	1.00000	.92051	.92051	1.00000	1.00000
3	1.00000	1.00000	.86275	.86275	1.00000	1.00000
4	1.00000	1.00000	1.00000	1.00000	.91096	.96342
5	1.00000	1.00000	1.00000	1.00000	.89180	.93395
6	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
7	.90146	.99227	.61079	.64152	.90146	.99228
8	.95989	.99292	.64201	.64201	.95989	.99293
9	1.00000	1.00000	.62041	.86788	1.00000	1.00000
10	.93508	.99194	.73849	.73849	.93508	.99059
11	1.00000	1.00000	.97518	.97518	.93083	.98087
12	1.00000	1.00000	.88881	.88881	1.00000	1.00000
13	.90002	.95494	.66723	.66723	.90002	.95494
14	.81411	.90167	.70088	.70088	.81411	.89874
15	.79550	.91643	.73049	.73949	.79550	.91437

* See Table 1 for designation of AMU; e.g., AMU 7 is 353 AMU, December 83.

UB = Upper Bound
LB = Lower Bound

TABLE VI

Correlation Results for AMU Data

	SORTIES	MC HOURS	NACFT	RNMCM	RNMCS	FDAYS	FIX RATE
Output 1	1.0000	.1235	.1859	-.3875	.2616	-.6289	-.1535
Output 2	.1235	1.0000	.9438	.0723	-.0860	-.3195	.0493
Input 1	.1859	.9438	1.0000	-.1002	-.2199	-.2295	-.0935
Input 2	-.3875	.0723	-.1002	1.0000	.2080	-.2019	.2103
Input 3	.2616	-.0860	-.2199	.2080	1.0000	-.2695	-.1958
Input 4	-.6289	-.3195	-.2295	-.2019	-.2695	1.0000	-.2124
Input 5	-.1535	.0493	-.0935	.2103	-.1958	-.2124	1.0000

MC = Mission Capable
NACFT = Number of Aircraft
RNMCM = Reciprocal of Not Mission Capable Maintenance
RNMCS = Reciprocal of Not Mission Capable Supply
FDAYS = Flying Days

The results presented in Table VI show that the inputs chosen were not significantly correlated with each other. Highly correlated inputs can be viewed as measuring the same thing and can be used interchangeably without affecting CFA results. In other words, if two input measures had been highly correlated, one could have been omitted without significantly altering the efficiency ratings (12).

Similarly, the output measures were not highly correlated with one another. However, the output called "sorties" was negatively correlated to the reciprocal of not mission capable maintenance, flying days, and fix rate inputs. The flying day input was also negatively correlated to output two. Apparently, an increase in the number of flying days does not correlate with increases in sortie production and mission capable time.

Aircraft Analysis

General Comments. A CFA analysis was performed on the simulated aircraft data discussed in Chapter II. The efficiency ratings for the aircraft analysis were compiled in Table VII. The aircraft analysis would have had more meaning if a large empirical data base had been used. However, the study did indicate that the use of aircraft as DMUs was feasible and worthy of follow-on analysis.

The same type of analysis as described for AMUs was performed for aircraft as well. Discussion of the aircraft results will be brief and will highlight a few interesting points. Referring to Figure 7, one interesting item is the comparison of aircraft 10 and 11 which have known characteristics. As mentioned in Chapter II, these units

TABLE VII

CFA Analysis for Aircraft Efficiency Ratings

	EFFICIENCY RATING			EFFICIENCY RATING	
AIRCRAFT	LB	UB	AIRCRAFT	LB	UB
1	1.00000	1.00000	15	1.00000	1.00000
2	1.00000	1.00000	16	.67185	.89178
3	.98433	.99794	17	.87971	.97681
4	1.00000	1.00000	18	1.00000	1.00000
5	1.00000	1.00000	19	1.00000	1.00000
6	1.00000	1.00000	20	.95852	.95852
7	1.00000	1.00000	21	.96831	.97643
8	1.00000	1.00000	22	1.00000	1.00000
9	1.00000	1.00000	23	1.00000	1.00000
10	1.00000	1.00000	24	1.00000	1.00000
11	.97090	.97090	25	1.00000	1.00000
12	.94037	.99232	26	1.00000	1.00000
13	1.00000	1.00000	27	1.00000	1.00000
14	1.00000	1.00000	28	1.00000	1.00000

UB = Upper Bound
LB = Lower Bound

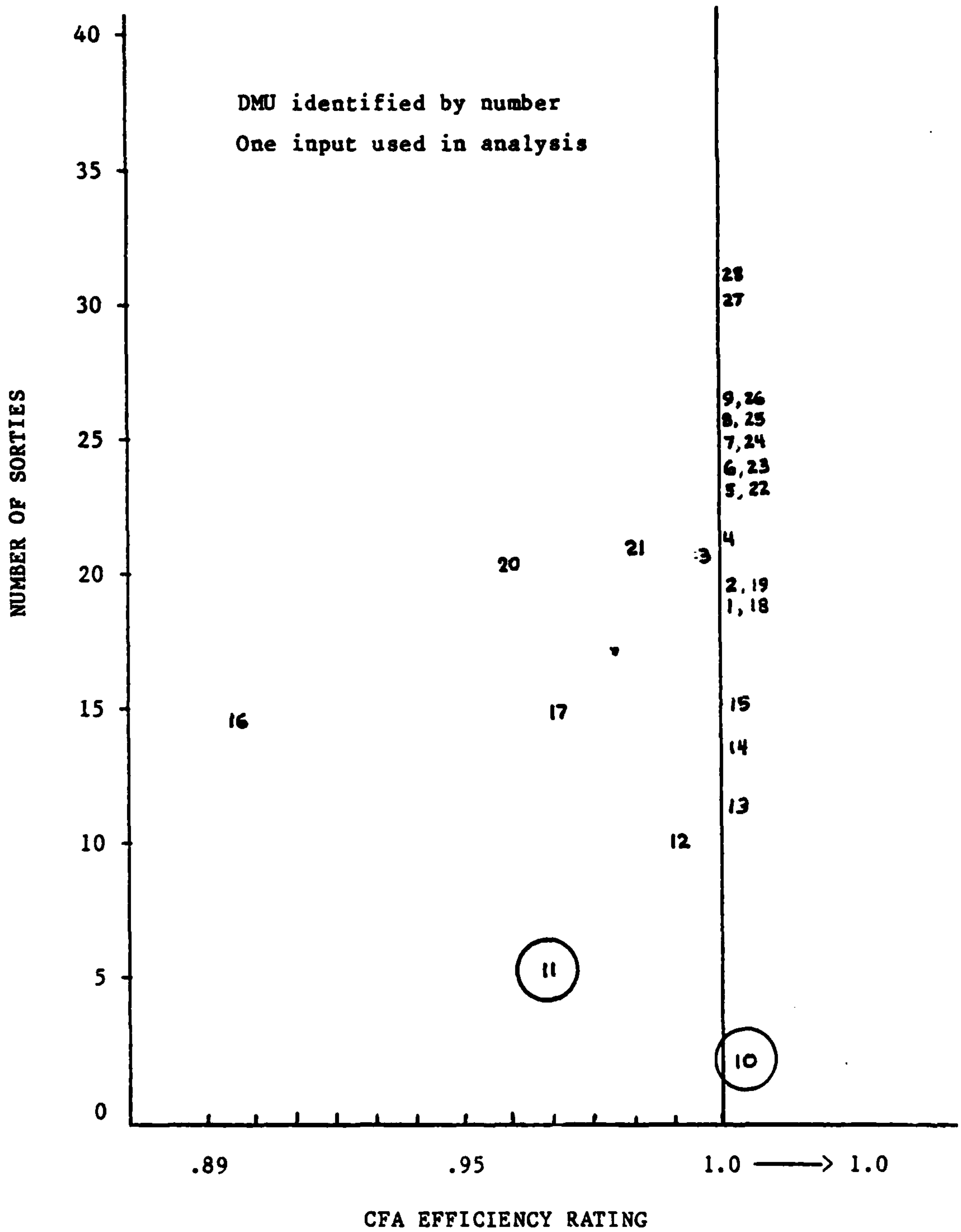

Figure 7. CFA Efficiency vs. Number of Sorties

represent hangar queens. Because these units were designated as hangar queens, this author expected them both to receive inefficient ratings. However, aircraft 10 was so unlike the other aircraft in terms of its mix of inputs and outputs, it was treated as an "outlier" and therefore achieved an efficient rating by ignoring some of the inputs. Specifically, Inputs 2 and 3, the reciprocals of NMCM and NMCS respectively, were so low that the model did not consider these inputs in rating aircraft 10. In this case, managers would want to perform further analysis of aircraft 10 performance which might require the combined use of judgment and the CFA and DEA analyses in order to determine whether or not aircraft 10 is truly efficient.

Aircraft Performance as a Measure of Unit Performance. An important area for future research is the aggregation of the individual aircraft performance ratings into a measure of unit performance. This would be desirable because aircraft measurements provide a means for objectively evaluating maintenance performance while focusing on aircraft performance as well. There are several possible ways to combine individual aircraft ratings into a unit rating that will be discussed in this section, including visual, ratio, and computer program assessments.

Visual Assessments. An easy way for a manager to get a feel for unit performance from analysis of individual aircraft is by graphing the efficiency rating of the aircraft and assessing this graph visually. An example of this type of analysis is shown in Figure 8. Note that aircraft from two units are represented and distinguished from one another. The ratings appear to be grouped by unit. A manager might conclude that unit X appears to have better overall performance.

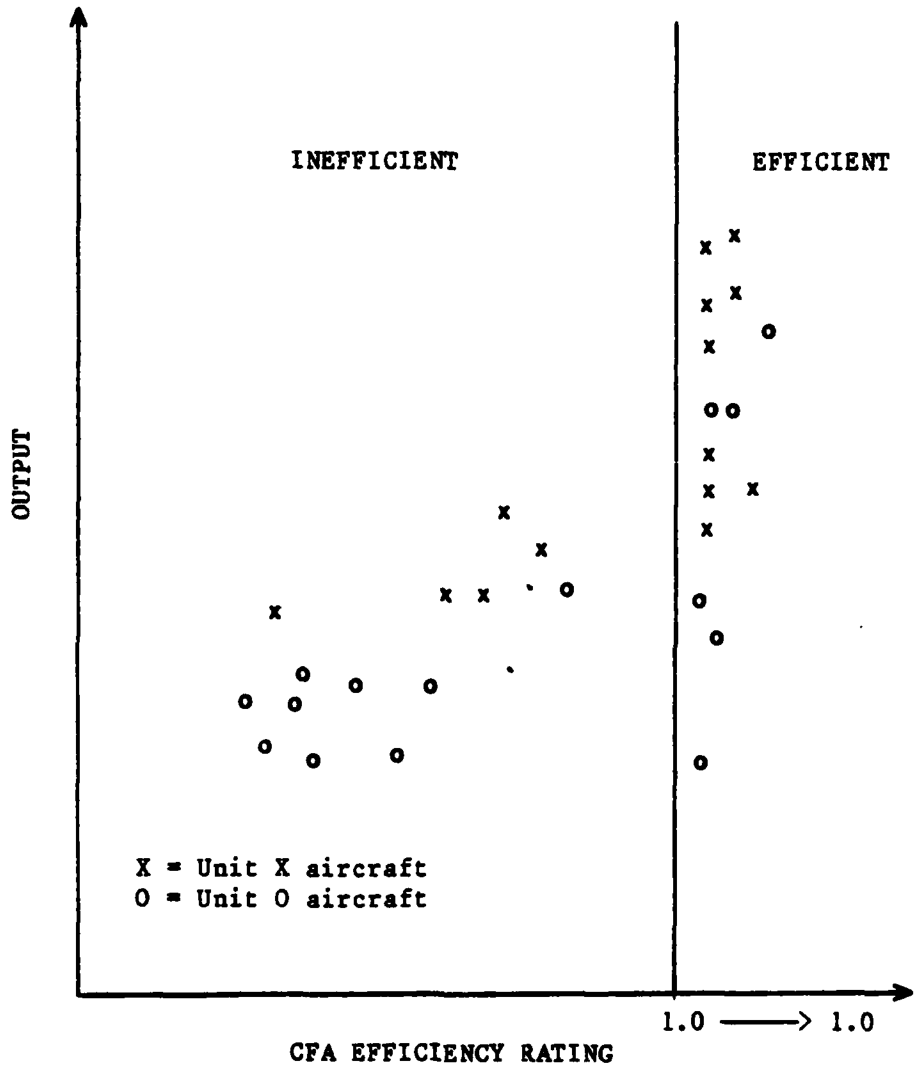

Figure 8. Proposed Visual Unit Comparison Based on Aircraft Evaluation

The visual assessment technique is a starting point for additional investigation. If results do not group into distinct areas on an efficiency versus output graph, additional techniques to assess unit performance would be required.

<u>Ratio Assessment</u>. After the visual assessment has been performed, a ratio assessment could also be performed. For example, units could be compared based on the average of individual ratings. If aircraft 1 through 14 of Table VII belong to unit A and if 15 through 28 belong to unit B, the upper bound efficiency ratings could be averaged as follows:

$$\frac{\sum \text{aircraft ratings}}{\text{number of aircraft}}$$

$$\begin{array}{l}\text{Unit A}\\\text{rating}\end{array} = \left(\frac{11\ (1.0) + .99794 + .97090 + .99232}{14}\right) = .9972$$

$$\begin{array}{l}\text{Unit B}\\\text{rating}\end{array} = \left(\frac{10\ (1.0) + .89178 + .97681 + .95832 + .97643}{14}\right) = .98595$$

Apparently, unit A is slightly more efficient in overall performance than unit B.

Another ratio that could be developed is the number of efficient aircraft divided by the total aircraft assigned. Using Figure 8 as a reference, we can compare units X and O based on their respective aircraft performance ratings:

$$\begin{array}{l}\text{Unit X}\\\text{rating}\end{array} = \frac{9 \text{ efficient aircraft} \times 100}{14 \text{ total aircraft/unit X}} = 64.3\% \text{ efficient}$$

$$\text{Unit O rating} = \frac{\text{6 efficient aircraft x 100}}{\text{14 total aircraft/unit X}} = \text{42.9\% efficient}$$

These methods of analysis give the manager another way to measure unit performance.

Computer Analysis. A third untried method for aggregating individual aircraft ratings into a measure of unit performance might be to use the individual aircraft ratings as inputs or outputs in a unit CFA analysis. For example, the percent of individual aircraft that were rated efficient in an aircraft CFA analysis could be viewed as an output of maintenance in a CFA analysis of the unit.

Summary

In summary, this researcher noted that the CFA analysis program gave useful information for maintenance managers. In using CFA and DEA it must be stressed that the programs are tools and not absolute answers. The models provide empirical evaluations of efficiency and suggest possible sources of inefficiency; however, use of the efficiency information will determine the value of the models for management.

Figure 9 summarizes the phases of analysis used in this thesis. Note that CFA analysis could be part of an iterative performance evaluation system. This thesis is an example of one analysis iteration for one aircraft maintenance unit. The basic analysis plan is applicable to all types of CFA analyses for performance evaluation and performance improvement programs.

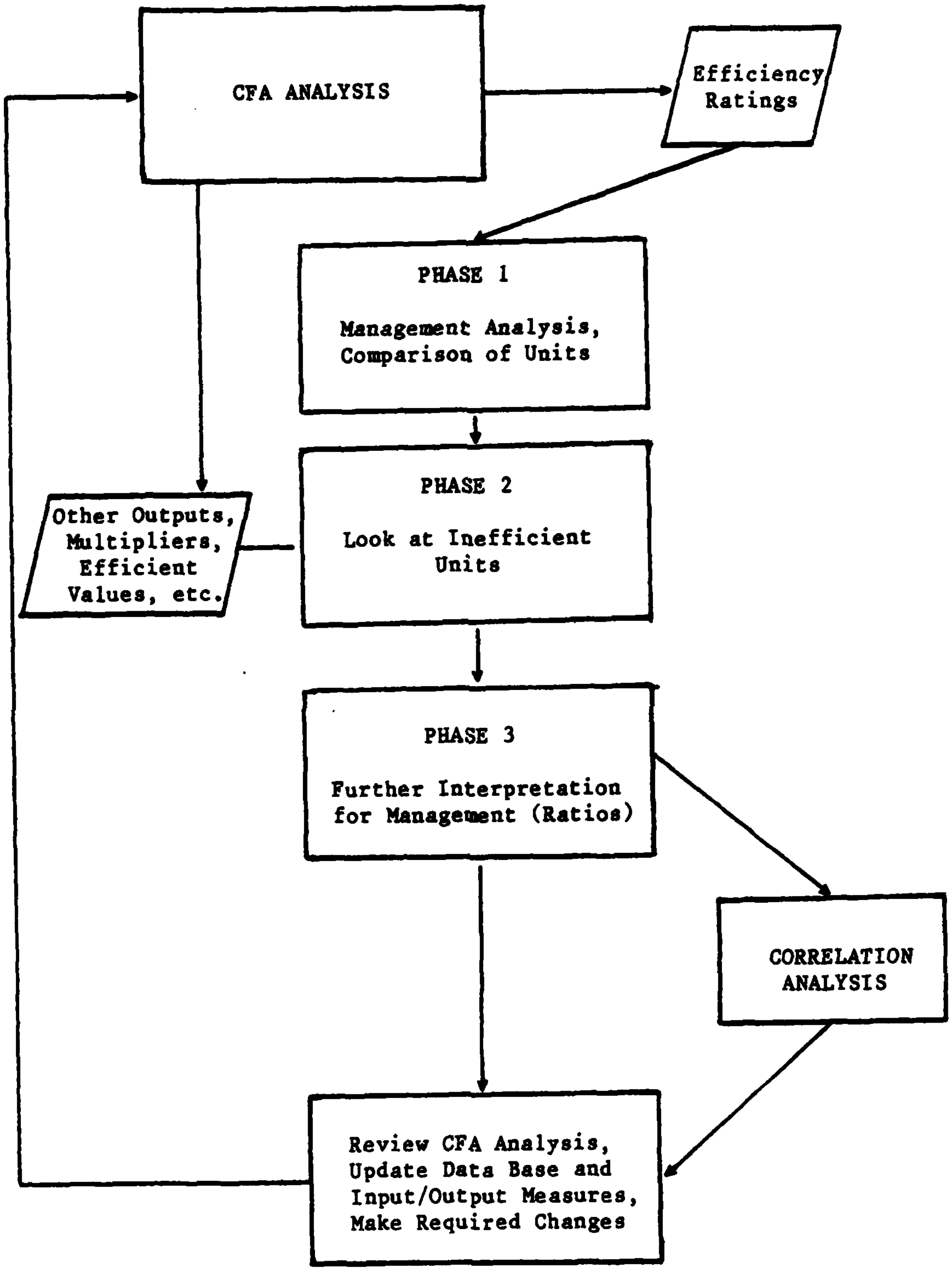

Figure 9. Analysis Flow Chart

IV. Conclusions and Recommendations

Introduction

Chapter IV is divided into two sections. The first, Conclusions, examines how effectively this thesis met the objectives outlined in Chapter I. The second section, Suggestions for Future Research, discusses the potential uses of the performance evaluation results in this thesis and identifies areas for further research including the need for CFA application to other areas of maintenance management.

Conclusions

This section is organized into four parts, each corresponding to the research objectives outlined in Chapter I.

Objective One. AMUs and aircraft can be evaluated using the CFA methodology. In this researcher's opinion, CFA exceeds performance evaluation techniques currently used in the field because its evaluations are empirically based and because CFA provides a significant amount of information which can be analyzed in a variety of ways.

Objective Two. Several methodologies were proposed for using individual aircraft analyses to measure unit performance. Additional research is needed before firm conclusions can be reached as to the feasibility of using these approaches. Future research should obtain empirical aircraft and unit data, use CFA to evaluate both, and then determine if the results of aggregating individual aircraft performances correspond to the measured unit performance.

Study of individual aircraft performance should continue to be a very fruitful area for research. Not only could this type of analysis contribute to evaluation of aircraft maintenance units but it could also pinpoint problem aircraft and problems in supply support.

Objective Three. Constrained Facet Analysis (CFA) proved to be applicable to Air Force performance evaluation. CFA could be used by maintenance managers as part of a performance evaluation plan, but managers should not use CFA or any other technique as the sole basis for their decisions. Caution must also be used to avoid over-emphasizing efficiency at the cost of effectiveness. Further, managers must recall that CFA computes relative rather than absolute efficiency measures.

CFA would be difficult for wing maintenance managers to use without training. However, continued refinement of the CFA computer programs would make it easier for wing level managers to use in the future. The usefulness of CFA would be enhanced if computer systems were available to enable the simultaneous evaluation of several wings. This would enable managers to compare several units and would spark healthy competition among units that would advance the efficiency frontier. A multi-unit system is currently being used in the Houston Independent School system, and Bessent and Bessent (6) report that school operations in Houston have improved as a result of CFA.

Objective Four. CFA information can be effectively translated for maintenance management use. CFA results aid in operational planning, resource allocation, and decision making, and they can also be converted to ratio measures currently used by managers for the above functions.

General Conclusions. In summary, Constrained Facet Analysis proved to be effective for evaluating aircraft maintenance units and aircraft. The results were more understandable than current methods of evaluating performance. CFA also provided useful suggestions for improvement which managers can consider when choosing among alternative courses of action.

Drawbacks to the use of CFA are that it will require training to implement and that, at this writing, the software is available only through the University of Texas at Austin. However, these problems can be overcome.

Suggestions for Future Research

Constrained Facet Analysis could have a widespread impact on maintenance management in the Air Force. Figure 10 is a matrix of the variety of management levels and functions which could benefit from CFA evaluations of units and aircraft. The four major levels of management are wing, major command, Air Force Logistics Command (AFLC), and Air Force. At each level CFA results could be used to support strategic, tactical, and daily operational decision making in areas such as resource allocation, operational planning, and capability assessment. Managers at all levels could use the CFA evaluations as a source of performance information which could help them plan improvements in their units and in the entire system. CFA might also be used for

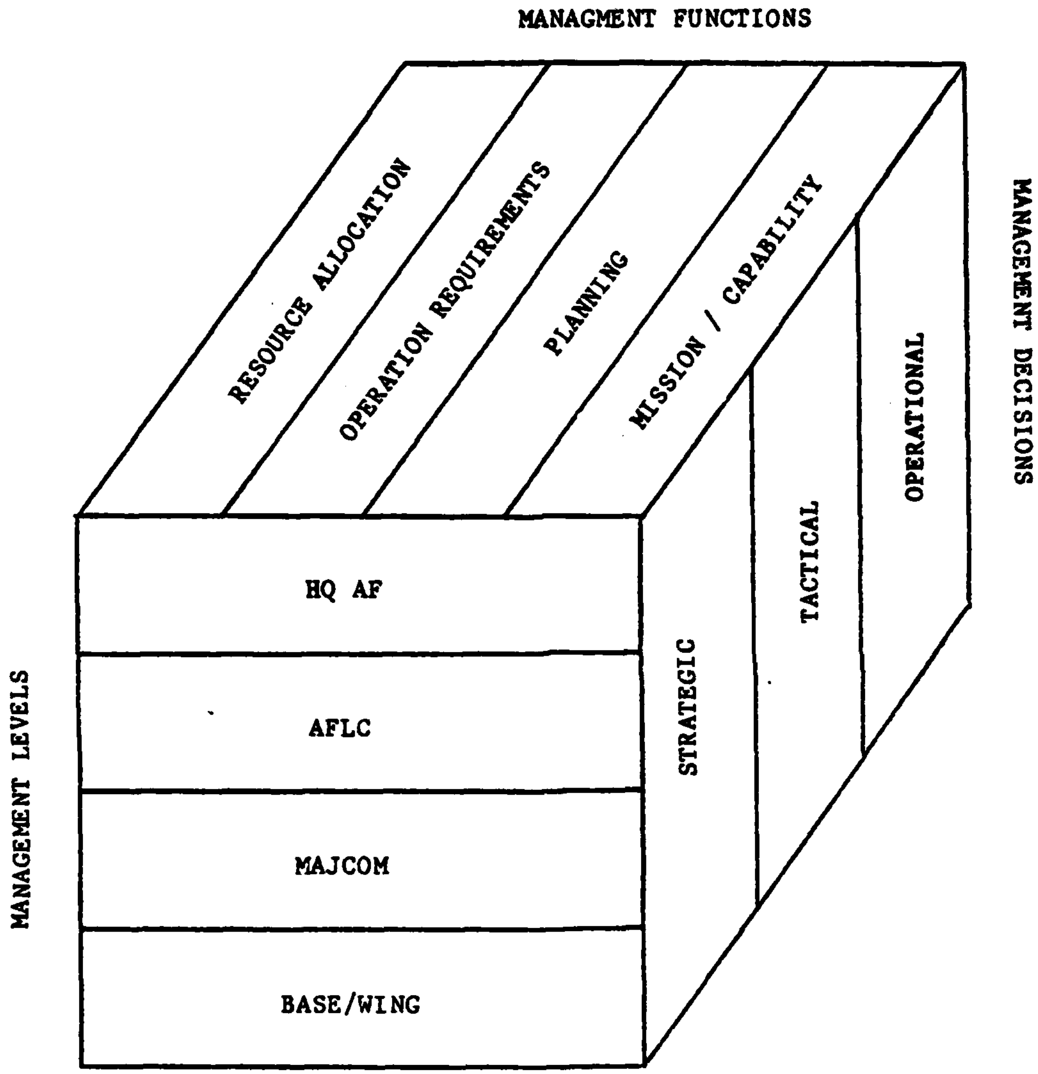

Figure 10. Management Matrix for Performance Evaluation Results

special applications in programs such as the Tactical Air Command (TAC) dedicated crew chief program. CFA evaluations of individual aircraft might be used to help evaluate the relative performance of crew chiefs.

This thesis highlighted the need for additional CFA analysis in the aircraft maintenance field. Future research is needed to refine the use of Constrained Facet Analysis in performing maintenance evaluations. These research needs include:

1. Obtaining more extensive data bases to evaluate units over longer periods of time to look for seasonal affects on performance.

2. Obtaining data bases on a variety of units to compare performance in different locations.

3. Performing research to identify better ways to select input and output measures.

4. Continuing to study the performance of individual aircraft and how individual aircraft performance ratings could be aggregated into a rating of unit performance.

Exploratory research to broaden the application of CFA to maintenance is also needed in the following areas:

1. Determining how to measure the support provided to AMUs by other units such as supply or off-equipment maintenance groups.

2. Comparing the performance of different year groups and different weapon systems.

3. Determining effects of extreme environments on performance, e.g., comparing how cold weather performance differs from performance in more temperate climates.

4. Extending the use of CFA to studies of missile and vehicle maintenance.

5. Performing CFA evaluations on the same units over time to detect advances of the efficiency frontier and to determine whether improvements in performance were caused by CFA feedback and managerial intervention.

In summary, there are many possible uses of CFA in maintenance management. CFA would give managers an advanced evaluation technique upon which to base decisions that affect performance.

Appendix: Acronyms Used

AFB	Air Force Base
AFIT	Air Force Institute of Technology
AFLC	Air Force Logistics Command
AFSC	Air Force Systems Command
AMU	Aircraft Maintenance Unit
CFA	Constrained Facet Analysis
CONUS	Continental United States
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DSS	Decision Support System
EMS	Equipment Maintenance Squadron
MC	Mission Capable
MCR	Multi Command Regulation
MTBF	Mean Time Before Failure
MTTR	Mean Time to Repair
NMCM	Not Mission Capable Maintenance
NMCS	Not Mission Capable Supply
OIC	Officer In Charge
TAC	Tactical Air Command
TFW	Tactical Fighter Wing
SIE	Sigma Iota Epsilon

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release;
distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFIT/GLM/LSM/84S-26

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
School of Systems and Logistics

6b. OFFICE SYMBOL *(If applicable)*
AFIT/LS

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State and ZIP Code)*
Air Force Institute of Technology
Wright-Patterson AFB, Ohio 45433

7b. ADDRESS *(City, State and ZIP Code)*

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State and ZIP Code)*

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.

11. TITLE *(Include Security Classification)*
See Box 19

12. PERSONAL AUTHOR(S)
Valerie J. Gonnerman, Captain, USAF

13a. TYPE OF REPORT
MS Thesis

13b. TIME COVERED
FROM ________ TO ________

14. DATE OF REPORT *(Yr., Mo., Day)*
1984 September

15. PAGE COUNT
73

16. SUPPLEMENTARY NOTATION

Approved for public release: IAW AFR 190-17.
LYNN E. WOLAVER 14 Sep 84
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

17. COSATI CODES

FIELD	GROUP	SUB. GR.
05	01	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Constrained Facet Analysis, Efficiency
Performance Evaluation, Effectiveness
Maintenance Management

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Title: PERFORMANCE EVALUATION OF A-10 AIRCRAFT
MAINTENANCE UNITS AND AIRCRAFT USING
CONSTRAINED FACET ANALYSIS

Thesis Advisor: Charles T. Clark, Lt Col, USAF

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Charles T. Clark, Lt Col, USAF

22b. TELEPHONE NUMBER *(Include Area Code)*
513-255-5023

22c. OFFICE SYMBOL
AFIT/LSM

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

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Performance evaluation is required to obtain important feedback on system efficiency for management decision making. For Air Force aircraft maintenance managers, performance evaluation is crucial for determining capability and evaluating unit efficiency and effectiveness. This thesis effort applied Constrained Facet Analysis (CFA), a linear fractional programming technique, to the performance evaluation of aircraft maintenance units (AMUs) and aircraft. Empirical data for three AMUs covering a five month period of time and simulated data for 28 aircraft was evaluated using the CFA and Data Envelopment Analysis (DEA) computer programs at the University of Texas. Results show that CFA and DEA can be used to evaluate relative efficiency of Air Force units.

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